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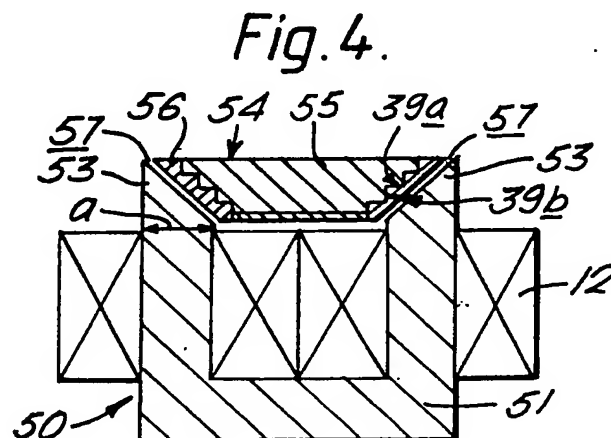
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(54) Magnetic actuator device

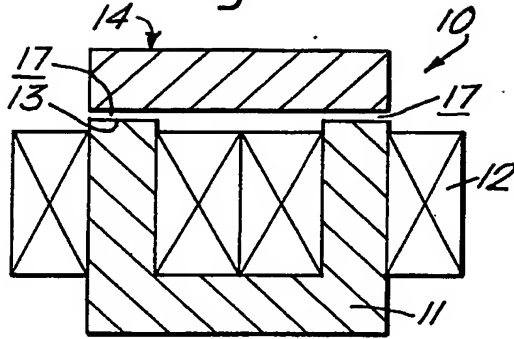
(57) A Magnetic actuator device 50 comprising magnetizable material 51 defining a gap 57 in which a magnetizable member 56 of a composite armature 54 is disposed and movable in a direction from one side of the gap 57 to the other side in response to changes in magnetization of the movable member 56 another part 55 of the armature being fixed. The member 56 at one side has shaped surfaces 39b extending generally in the direction of movement of the member 56 and which overlap in abutting or near adjacent relationship shaped surfaces 39a of the material 51 throughout the movement of the member 56. The overlapping surfaces 39a, 39b provide a path for magnetic flux in operation of the device 50, so that an asymmetric

magnetic field is distributed about the member 56 in the direction of movement causing the member 56 to move across the gap 57. In other arrangements the armature follows a curved path.

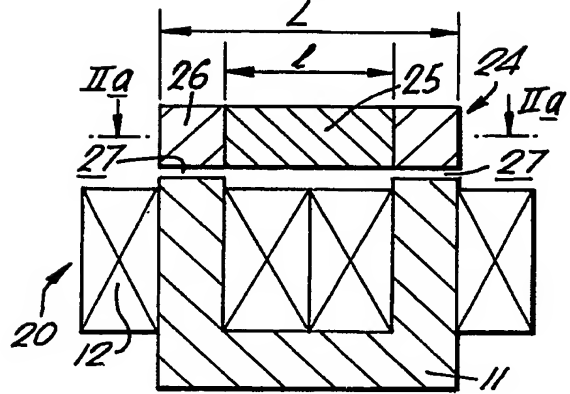


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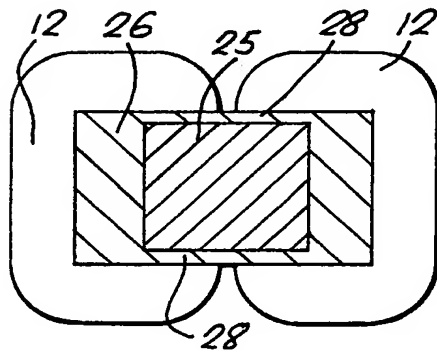
*Fig. 1.*



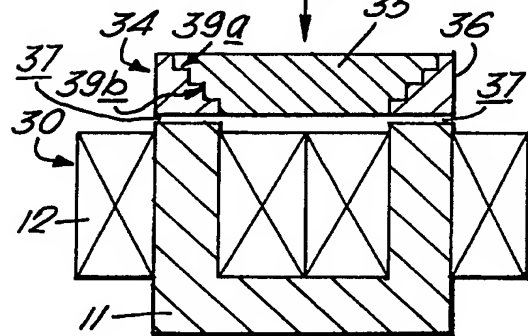
*Fig. 2.*



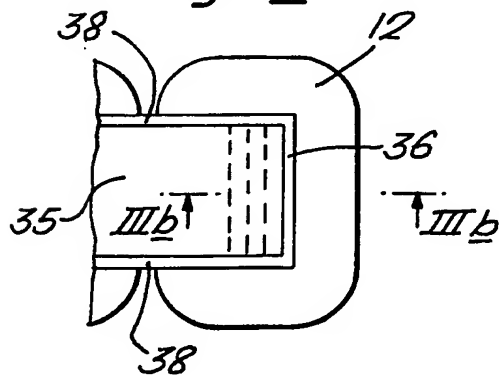
*Fig. 2a.*



*Fig. 3.*



*Fig. 3a.*



*Fig. 3b.*

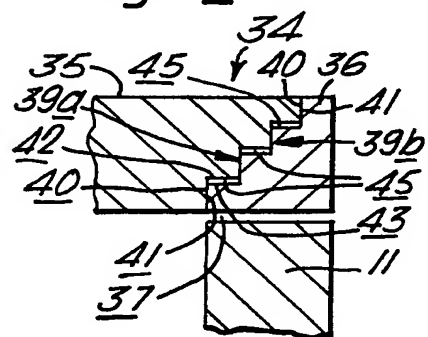


Fig. 4.

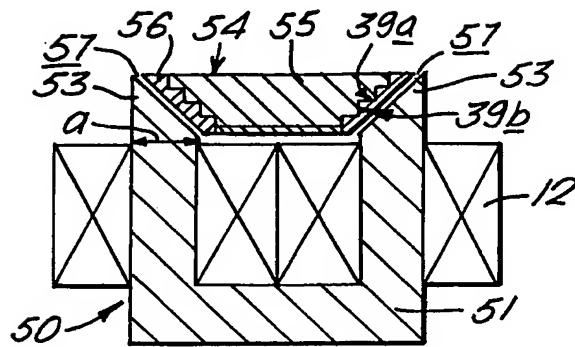


Fig. 5.

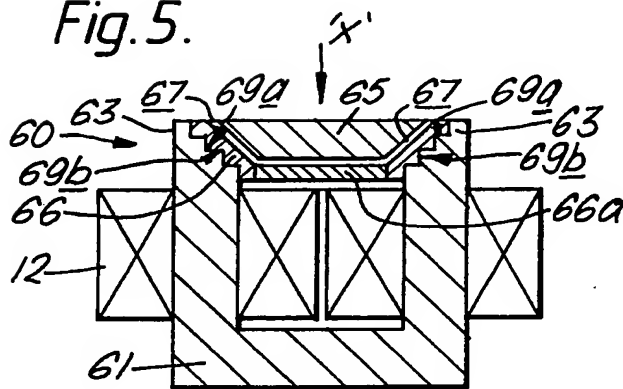


Fig. 5a.

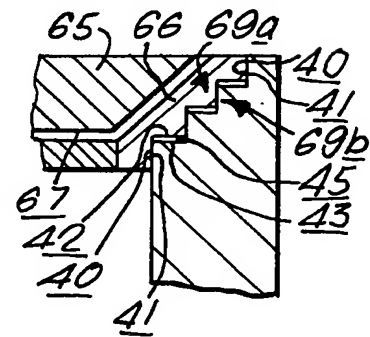
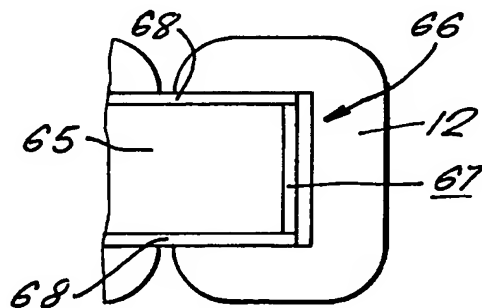
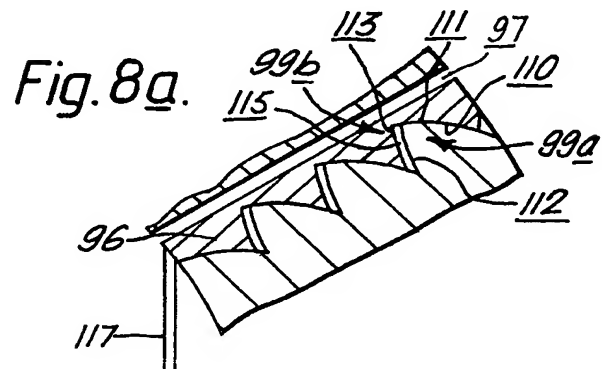
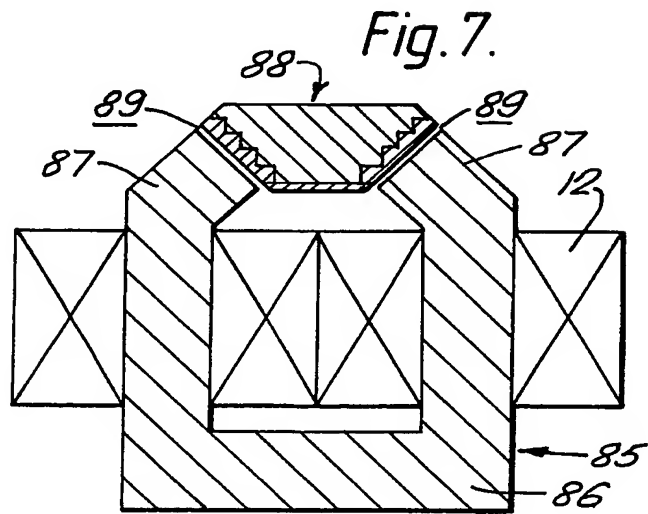
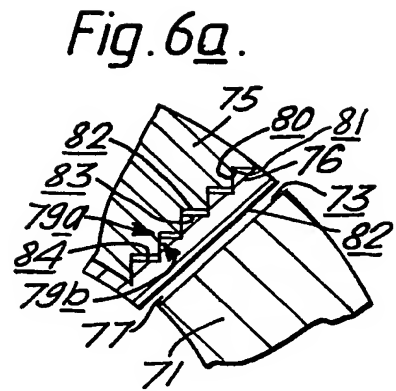
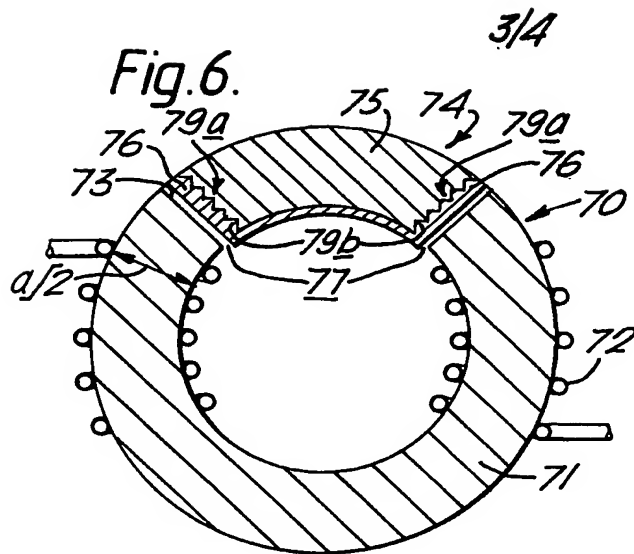
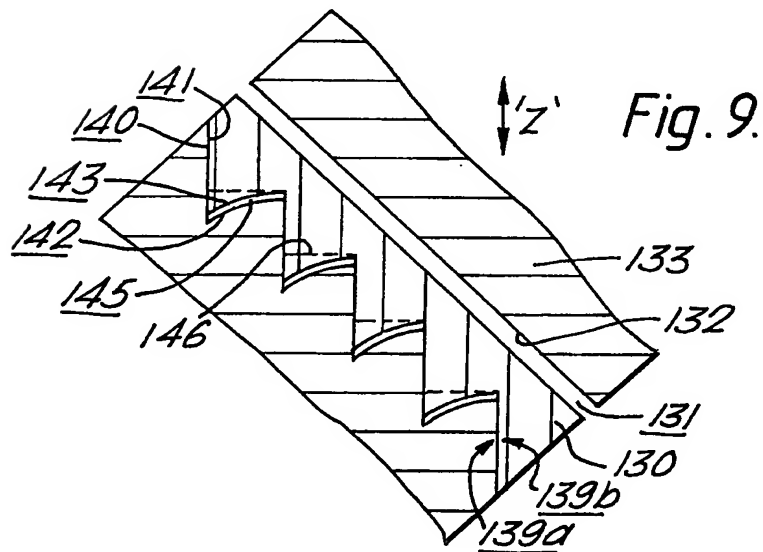


Fig. 5b.







## SPECIFICATION

**Magnetic actuator device**

5 This invention relates to a magnetic actuator device for moving a magnetizable member under the influence of a magnetic force, for example a solenoid.

10 In order to obtain the largest magnetic force and, therefore, the fastest operation in a given size of known such devices, the magnetic flux density in the fully energised state is usually made as high as can be efficiently obtained with the magnetic material used. Any further  
15 increase in magnetic force would require an increase in the size of the device, but a basic characteristic of such devices is that when the size is increased the mass of the movable member increases proportionally with the cube of the linear dimensions of the movable member whereas the magnetic force on the  
20 movable member increases proportionally only with the square of the linear dimensions thereof.

25 The invention therefore in one aspect provides a magnetic actuator device for providing movement of a magnetizable member in response to changes in magnetization, the device comprising magnetizable material  
30 defining a gap, and means for varying the magnetization of the material, the magnetizable member being locatable in the gap and movable in a direction from one side of the gap towards the other side thereof in response  
35 to changes in the magnetization of the material, and the member having a plurality of surfaces at one side thereof aligned substantially in said direction, which surfaces throughout the movement of the member in  
40 response to said changes in magnetization overlap adjacent surfaces of the material so as to provide a path for magnetic flux through the overlapped surfaces.

45 The proportion of the total surface of the said magnetizable member on the said one side thereof comprised by the said plurality of surfaces is desirably such that the movement causes substantially less change in energy of the magnetization on said one side than on  
50 the other side where overlapping surfaces of the member and the material in the direction of movement may be absent.

55 The invention in another aspect provides a magnetic actuator device for providing movement of a magnetizable member in response to changes in magnetization, the device comprising magnetizable material defining a gap,  
60 means for changing the magnetization of the material, and a magnetizable member locatable in the gap and movable in a direction from one side of the gap to the other side thereof in response to said changes in magnetization, the member at one side thereof  
65 and the magnetizable material at that side of the gap adjacent to said one side of the

member having surfaces shaped to overlap each other generally in said direction, thereby in operation producing an asymmetric distribution of the magnetization about the member  
70 in said direction and causing the member to move towards the other side of the gap under the influence of the asymmetric magnetization.

The invention may with advantage be incorporated in a magnetic actuator provided by a  
75 solenoid, for example a solenoid for exerting a relatively large force over a short stroke. Thus the invention further includes a solenoid comprising a stator and an armature, wherein the  
80 armature is of composite construction comprising a stationary portion thereof and a portion of the armature movable towards or away from the stator under the effect of the magnetization on the movable portion, and  
85 the movable portion having shaped surfaces at one side thereof so as to overlap correspondingly shaped surfaces of the stationary portion or of the stator, and thereby in operation producing an asymmetric energy of magneti-  
90 zation about the movable portion so as to move the movable portion away from said shaped surfaces under the influence of the asymmetric magnetization.

In the aforesaid aspects of the invention,  
95 return movement of the member may be effected by resilient biasing means. The overlapped surfaces may be in abutting relationship or near adjacent relationship, and the direction might extend linearly or arcuately,  
100 the overlapped surfaces being parallel to or concentric with said direction. Desirably, the overlapped surfaces are provided by portions of a plurality of complementary steps, and each step might have an acute included angle. It is advantageous for the gap to extend  
105 normal to the direction of the magnetic flux in the magnetizable material at said other side of the gap, although if desired the gap may extend angularly to said direction of the magnetic flux. The shaped surfaces and the correspondingly shaped surfaces of the solenoid of the invention may be substantially of zig-zag or sawtooth form, and it will be understood that the invention includes an armature  
110 adapted for the solenoid of the invention.  
115

The invention will now be further described by way of example only with reference to the accompanying diagrammatic drawings, in which:—

120 *Figure 1* shows a side view of a magnetic actuator device in the form of a conventional solenoid;

*Figure 2* shows a side view in medial section of the solenoid of *Figure 1* modified to  
125 incorporate the invention;

*Figure 2a* shows a sectional view on the line IIa-IIa of *Fig. 2*;

*Figure 3* shows a side view in medial section of a modified form of the solenoid of *Fig. 2*;  
130

Figure 3a shows a fragmentary view in the direction of arrow 'A' of Fig. 3;

Figure 3b shows to an enlarged scale a fragmentary sectional view on the line IIIb-IIIb of Fig. 3a;

Figure 4 shows a side view in medial section of a modified form of the solenoid of Fig. 3;

Figure 5 shows a side view in medial section of another modified form of the solenoid of Fig. 3;

Figure 5a shows to an enlarged scale part of the view of Fig. 5;

Figure 5b shows a fragmentary view in the direction of arrow 'X' of Fig. 5;

Figure 6 shows a side view in medial section of an alternative magnetic actuator device to that of Fig. 1 and incorporating the invention;

Figure 6a shows to an enlarged scale part of the view of Fig. 6;

Figure 7 shows a side view in medial section of a modified form of the solenoid of Fig. 4;

Figure 8 shows a side view in medial section of another alternative magnetic actuator device;

Figure 8a shows to an enlarged scale part of the view of Fig. 8; and

Figure 9 shows a fragmentary side sectional view of yet another magnetic actuator device.

In the above Figures, like parts have like numerals.

Referring now to Fig. 1, a solenoid 10 is shown and comprises, a U-shaped stator 11 having windings 12, and an armature 14 which defines parallel gaps 17 between pole piece ends 13 of the stator 11.

In operation, on the windings 12 being energised in a conventional manner, the armature 14 is attracted by and moves towards the stator 11 under the action of the magnetic force arising in the gaps 17. On the windings 12 being de-energised so that the magnetic flux decays, the armature 14 is arranged to be moved away from the stator by resilient means (not shown). As aforementioned, for high speed operation the essential requirement is for a high ratio of magnetic attractive force to mass (and thus to volume) of the armature 14, which is not readily attained with such solenoids 10.

In Figs. 2 and 2a, a solenoid 20 is shown having a stator 11 and windings 12 identical to those of Fig. 1, but having an armature 24 of composite construction. The armature 24 comprises a stationary portion 25 which is held by a support (not shown), and an annular movable member 26 having thin side cheeks 28 and which locates as a sliding fit about the stationary portion 25. Most of the volume of the movable member 26 is concentrated opposite ends 13 of the stator 11 to define parallel gaps 27 therebetween.

In operation, on the windings 12 being

energised, the only appreciable magnetic force on the movable member 26 is that arising in the gaps 27, since the adjacent surfaces of the movable member 26 and the stationary portion 25 provide a path for magnetic flux. An asymmetric magnetic field is, therefore, distributed about the movable member 26 in the direction of movement of the movable member 26 such that it is attracted by and moves towards the stator 11, being returned by resilient means (not shown) on the windings 12 being de-energised.

The magnetic force on the armature 24 is the same as that experienced by the armature 14 of Fig. 1, but the moving part of the armature 24 (i.e. the movable member 26) has decreased in the ratio  $(L-1)L$ , and thus the force/volume ratio has improved by approximately the ratio of  $L/(L-1)$  where as shown in Figure 2:-

$L$  = width of the movable member 26

$l$  = width of the stationary portion 25

In Figures 3 and 3a, a solenoid 30 is shown which in many respects is similar to the solenoid 20 of Fig. 2 in having a stator 11 with windings 12, but has a composite armature 34 which defines parallel gaps 37 therebetween the stator 11, and has a stationary portion 35 disposed within a hollow movable portion 36 provided with thin side cheeks 38. The stationary portion 35 and the movable member 36 interengage at which end thereof through a series of complementary steps 29a, 39b respectively extending angularly across the movable member 36. As shown in Fig. 3b, each step 39a, 39b is formed by abutting slider surfaces 40, 41 respectively aligned parallel to the intended direction of movement of the movable member 36 and opposing surfaces 42, 43 respectively which extend perpendicular to the slider surfaces 40, 41 to define gaps 45 between the opposing surfaces 42, 43.

In operation, on the windings 12 being energised, an asymmetric magnetic field is distributed about the movable member 36 in the direction of movement of the movable member 36, since the gaps 45 carry very little magnetic flux, being by-passed by the slider surfaces 40, 41. The only appreciable magnetic force on the movable member 36 is that arising in the gaps 37 so that the movable member 36 is attracted towards the stator 11, and is returned by resilient means (not shown) on the windings 12 being de-energised.

The magnetic force on the movable member 36 is the same as that on the movable member 26 of Fig. 2, but the volume of the movable member 36 has been reduced by a factor of approximately two so that the force/volume ratio has been increased approximately by a factor of two.

In Fig. 4, a solenoid 50 is shown which is similar in most respects to the solenoid 30 of Fig. 3, but has a stator 51 with windings 12 and with pole piece ends 53 each having faces inclined at about 45° to define between them a truncate V-shaped opening having an included angle of about 90° and in which a composite armature 54 is disposed. The armature 54 comprises a stationary portion 55 similar to the stationary portion 35 of Fig. 3, and a hollow movable member 56 which is similar in most respects to the movable member 36 of Fig. 3 but is relieved to correspond with the pole piece ends 53 and define parallel gaps 57 therebetween. The stationary portion 55 and the movable member 56 interengage through an angular series of complementary steps 39a, 39b identical to the steps 39a, 39b of Fig. 3.

The solenoid 50 of Fig. 4 operates in a similar manner to the solenoid 30 of Fig. 3, an asymmetric magnetic field being distributed about the movable member 56 in the direction of movement of the movable member 56 to attract it towards the stator 51 on the windings 12 being energised. However, the inclination of the pole piece ends 53 of the stator 51 results in a reduction of the magnetic force on the movable member 56 by a factor of two in comparison with the magnetic force on the movable member 36 of Fig. 3, but the volume of the movable member 56 can be reduced by a factor greater than two and depends on the ratio of length of the gap 57 to the width of the pole piece ends 53.

It will be understood that the angle of inclination of the pole piece ends 53 may be changed, the more acute the angle the greater the movement of the movable member 56 across the gap 57.

As an alternative to the arrangement of complementary steps 59a, 59b between the stationary portion 55 and the movable member 56 of Fig. 4, the arrangement may be inverted as shown in Fig. 5 to which reference is made. In Fig. 5 a solenoid 60 is shown comprising a stator 61 having windings 12 and similar in most respects to the stator 51 of Figure 4, but has pole piece ends 63 which are shaped to provide an angular series of steps 69b which interengage a complementary series of steps 69a in a hollow movable member 66 of a composite armature 64 having a stationary portion 65. The steps 69a, 69b as shown in Fig. 5a are identical in form to the steps 59a, 59b of Figs. 4 and 4b, and have abutting slider surfaces 40, 41 respectively, and opposing surfaces 42, 43 respectively defining gaps 45 therebetween. The stationary portion 65 is of truncated V-shape and defines a parallel gap 67 at each end thereof between similarly inclined surfaces of the movable member 66. To avoid by-passing the magnetic flux away from the gaps 67, the

movable member 66 has a non-magnetic base portion 66a and, as shown in Fig. 5b, non-magnetic side cheeks 68.

The solenoid 60 operates in a similar manner to that described in relation to the solenoid 50 of Fig. 4. On the windings 12 being energised, an asymmetric magnetic field is distributed about the movable member 66 in the direction of movement of the movable member 66 which is attracted by and moves towards the stationary portion 65. The magnetic force on the movable member 66, and the volume of the moveable member 66, are approximately the same as those of the movable member 56 of Fig. 4.

The invention may be incorporated in magnetic actuator devices of alternative shape to those aforescribed, for example as shown in Figure 6 to which reference is now made. In Fig. 6 a solenoid 70 is shown having a stator 71 of part-annular form and arranged to be energised by windings 72. The radial thickness of the stator 71 is greater by a factor of  $\sqrt{2}$  than the width 'a' of the pole end pieces 53 of the stator 51 of Fig. 4, and has radially extending pole piece ends 73 which define a sector having an included angle of about 90° into which a composite armature 74 is disposed, the armature 74 being shaped to correspond with the omitted sector of the annulus defined by the stator 71. The armature 74 comprises a stationary portion 75, and a hollow movable member 76, which interengage through an angular series of complementary steps 79a, 79b respectively similar to the steps 39a, 39b of Fig. 3. As shown in Fig. 6a, the steps 79a, 79b are provided by abutting slider surfaces 80, 81 respectively extending parallel to a bisector of the sector defined by the pole end pieces 73, and opposing surfaces 82, 83 respectively extending perpendicular to the slider surfaces 80, 81 and defining gaps 84 between the opposing surfaces 82, 83. The movable member 76 has side cheeks (not shown) and inclined end faces 82 which define parallel gaps 77 between the end faces 73 of the stator 71.

In operation, on the windings 72 being energised, an asymmetric magnetic field is distributed about the movable member 76 which is attracted by and moves towards the stator 71. The magnetic force acting on the movable member 76 is twice as great as that in respect of the movable member 26 and 36 of Figs. 2 and 3 respectively, whilst the scope for a reduction in volume of the movable member 76 is the same as that for the movable member 56 of Fig. 4. The annular shape of the stator 71 allows the width of the gap 77, and another example of such a magnetic actuator device having the axes of the pole piece ends of the stator normal to the parallel gaps is shown in Fig. 7.

Referring to Fig. 7, a solenoid 85 is shown



comprising a stator 86 having windings 12 and similar in many respects to the stator 51 of Fig. 4, but the stator 86 is partially closed and shaped to provide inclined pole piece ends 87 between which is disposed a composite armature 88 identical in most respects to the composite armature 54 of Fig. 4, to define parallel gaps 89 therebetween the stator 86.

The solenoid 85 functions in a similar manner to that described in relation to the solenoid 50 of Fig. 4, but the full saturation value of the pole piece ends 87 is provided across the gaps 89 because the path of the magnetic flux through the pole piece ends 87 is normal to the parallel gaps 89 unlike the solenoids of Figs. 4 and 5 in which the parallel gaps 57, 67 are inclined to the flux path.

The invention may also be incorporated in magnetic actuator devices to provide a rotary movement, for example as shown in Fig. 8 in which a magnetic actuator device 90 is shown comprising a ring-shaped stator 91 having windings 92 and generally of rectangular cross-section. A movable member 96 of magnetizable material at one side thereof interengages the stator 91 through a radially extending series of steps 99a, 99b. The other side of the movable member 96 is flat and defines a parallel, generally radially extending gap 97 between a flat pole end 93 of the stator 91. The steps 99a, 99b as shown in Fig. 8a, have abutting, arcuate slider surfaces 110, 111 respectively extending on corresponding pitch circles centred at 119 which is displaced from the centre of the stator 91, and arcuate opposing surfaces 112, 113 respectively which define arcuate gaps 115 between them and extend at an acute included angle to the respective slider surfaces 110, 111. The movable member 96 is supported by a link 117 which is restrained by a resilient means in the form of a compression spring 120 and extends from a rod 118 pivoted at 119 so as to allow the slider surfaces 110, 111 to slide over each other as the movable member 96 pivots between the steps 99a and the pole end 93 of the stator 91.

In operation, on the windings 92 being energised, an asymmetric magnetic field is distributed about the movable member 96 such that the movable member 96 is attracted by and moves towards the pole end 93, thereby rotating the link 117 and thus the rod 118, and is subsequently pushed away from the pole end 93 by the compression spring 120 on the windings 92 being de-energised.

It will be understood that if desired the opposing surfaces 42, 43, and 82, 83 of Figures 3 and 6 respectively may extend obliquely to the corresponding slider surfaces 40, 41 or 80, 81 to define an acute angle therebetween, and although it is preferred to have the slider surfaces 40, 41, 80, 81, or 110, 111 respectively in abutting relation-

ship, if desired they may be spaced slightly apart to define a relatively narrow gap therebetween. One of the advantages of the opposing surfaces defining acute angles between the respective slider surfaces is that it allows the slider surfaces to be longer, and thus exposes a greater cross-sectional area of the slider surfaces to the magnetic flux so that a more uniform cross-section may be maintained for the magnetic flux during the movement of the movable member. This aspect is shown in more detail in Fig. 9 to which reference is now made. In Fig. 9 a movable member 130 is shown defining at one side thereof a parallel gap 131 between an opposing pole piece end 132 of an annular stator 133. The other side of the movable member 130 is shaped to define steps 139b which interengage corresponding steps 139a of the stator 133. The steps 139a, 139b comprise abutting flat slider surfaces 140, 141 which extend parallel to the direction of movement of the movable member 130 and which is indicated by the arrow 'Z' of Fig. 9. Arcuate opposing surfaces 142, 143 define arcuate gaps 145 therebetween and extend at an acute included angle to the respective slider surfaces 140, 141. A broken line 146 extends perpendicular to each slider surface 140, 141 to indicate the additional length of the slider surfaces 140, 141 gained by the feature of having an acute included angle between the slider surfaces 140, 141 and the opposing surfaces 142, 143.

The aforescribed stators and stationary portions of the armature are preferably of laminated construction to reduce eddy current losses, and together with the movable member are desirably made of relatively high resistivity and permeability magnetizable material.

It will be appreciated that although not aforescribed, the linear movement of the movable members may be used to effect a displacement of an element of a system.

Where desired, guide means (not shown) may be provided to restrain lateral displacement of the movable member.

#### CLAIMS

1. A magnetic actuator device for providing movement of a magnetizable member in response to changes in magnetization, the device comprising magnetizable material defining a gap, means for changing the magnetization of the material, and a magnetizable member locatable in the gap and movable in a direction from one side of the gap to the other side thereof in response to said changes in magnetization, the member at one side thereof and the magnetizable material at that side of the gap adjacent to said one side of the member having surfaces shaped to overlap each other generally in said direction, thereby in operation producing an asymmetric distribution of the magnetization about the

member in said direction and causing the member to move towards the other side of the gap under the influence of the asymmetric magnetization.

2. A magnetic actuator device for providing movement of a magnetizable member in response to changes in magnetization, the device comprising magnetizable material defining a gap, and means for varying the magnetization of the material, the magnetizable member being locatable in the gap and movable in a direction from one side of the gap towards the other side thereof in response to changes in the magnetization of the material, and the member having a plurality of surfaces at one side thereof aligned substantially in said direction, which surfaces throughout the movement of the member in response to said changes in magnetization overlap adjacent surfaces of the material so as to provide a path for magnetic flux through the overlapped surfaces.

3. A device as claimed in Claim 2, wherein the proportion of the total surface of the said magnetizable member on the said one side thereof comprised by the said plurality of surfaces is desirably such that the movement causes substantially less change in energy of the magnetization on said one side than on the other side where overlapping surfaces of the member and the material in the direction of movement may be absent.

4. A device as claimed in any one of Claims 1 to 3, wherein the overlapped surfaces are in abutting relationship.

5. A device as claimed in any one of Claims 1 to 3, wherein the overlapped surfaces are in near adjacent relationship.

6. A device as claimed in any one of the preceding Claims, wherein said direction extends linearly, and the overlapped surfaces are substantially parallel to the linear said direction.

7. A device as claimed in any one of Claims 1 to 5, wherein said direction extends arcuately, and the overlapped surfaces are substantially concentric with the arcuate said direction.

8. A device as claimed in Claim 6 or Claim 7, wherein said direction extends angularly with respect to the gap.

9. A device as claimed in any one of the preceding Claims, wherein the gap is aligned substantially normal with respect to the direction of the magnetic flux in the magnetizable material at said other side of the gap.

10. A device as claimed in any one of Claims 1 to 8, wherein the gap is angularly aligned with respect to the direction of the magnetic flux in the magnetizable material at said other side of the gap.

11. A device as claimed in any one of the preceding Claims, wherein the overlapped surfaces comprise portions of a plurality of complementary steps.

12. A device as claimed in Claim 11, wherein each step has an acute included angle.

13. A device as claimed in Claim 12, wherein at least another portion of each step at the included angle is of arcuate form.

14. A device as claimed in any one of Claims 11 to 13, wherein the member is of hollow form, and said overlapped surfaces are at each end of the member.

15. A device as claimed in any one of the preceding Claims, wherein return movement of the member is effected by resilient biasing means.

16. A magnetic actuator device provided by a solenoid comprising a stator and an armature, wherein the armature is of composite construction comprising a stationary portion thereof and a portion of the armature movable towards or away from the stator under the effect of the magnetization on the movable portion, and the movable portion having shaped surfaces at one side thereof so as to overlap correspondingly shaped surfaces of the stationary portion or of the stator, and thereby in operation producing an asymmetric energy of magnetization about the movable portion so as to move the movable portion away from said shaped surfaces under the influence of the asymmetric magnetization.

17. A device as claimed in Claim 16, wherein the movable portion is of annular form and disposed about the stationary portion.

18. A device as claimed in Claim 16, wherein the stator and the armature provide complementary portions of a substantially annular shaped device.

19. A device as claimed in Claim 16 or Claim 17, wherein the movable portion is of hollow form and the stationary portion is locatable in the movable portion.

20. A device as claimed in any of Claim 16 to 19, wherein the shaped surfaces and the correspondingly shaped surfaces comprise regions of complementary steps.

21. A device as claimed in any one of Claims 16 to 19, wherein the shaped surfaces and the correspondingly shaped surfaces are substantially of zig-zag or sawtooth form.

22. A device as claimed in Claim 16, wherein the movable portion is connectable to a pivotable link.

23. In or for a device as claimed in any one of Claims 16 to 22, an armature adapted therefor, the armature being of composite construction comprising a stationary portion thereof and a portion of the armature movable towards or away from the stator under the effect of the magnetization on the movable portion, the movable portion being shaped at one side thereof so as to overlap shaped surfaces of the stationary portion, thereby in operation producing an asymmetric energy of magnetization about the movable portion so

as to move the movable portion away from said shaped surfaces under the influence of the asymmetric magnetization.

24. A magnetic actuator device substantially as hereinbefore described with reference to Figs. 3, 3*a* and 3*b*, or Fig. 4, or Figs. 5, 5*a* and 5*b*, or Figs. 6 and 6*a* or Fig. 7 of the accompanying drawings.

25. A device as claimed in Claim 24 and modified substantially as hereinbefore described with reference to Fig. 9 of the accompanying drawings.

26. A magnetic actuator device substantially as hereinbefore described with reference to Figs. 8 and 8*a* of the accompanying drawings.

27. A system having at least one element arranged to be displaced by a device as claimed in any one of Claims 1 to 22, or 24 to 26.